Physical Variability in the Louisiana Inner Shelf Hypoxia Region

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Abstract

The inner shelf of the northern Gulf of Mexico from the Mississippi River Delta westward to the Texas-Louisiana border is the site of the highly stratified Louisiana Coastal Current fed by the Mississippi River system. The initial efflux of water from the mouths of the Mississippi River occurs as highly stratified plumes. Lagrangian measurements within the plume of Southwest Pass are consistent with concurrent satellite imagery. Nutrient distribution patterns are similar to those of physical parameters and suggest conservative dilution during the first day following nutrient release from the river mouth. After the waters attach to the coast to form the Louisiana Coastal Current, they tend to flow westward, although they do respond to wind shifts on periods of a few days or longer. The physical structure of this region is dominated by the strength and phasing of river discharge and wind forcing. This structure exerts a strong control on the distribution of hypoxia and the processes responsible for its spatial and temporal variability.

Introduction

The Mississippi-Atchafalaya River system constitutes the dominant control on the oceanographic character of the Louisiana inner shelf. This river system drains 43 percent of the contiguous United States and parts of two Canadian provinces. It delivers, on average, approximately 635 km^3 of fresh water to the shelf each year, as well as massive amounts of suspended sediment and dissolved nutrients. Peak discharge occurs in the spring. Thirty percent of this water enters the Gulf through the Atchafalaya River and the remainder through the Mississippi River delta. Of this latter volume, the amount flowing onto the west Louisiana shelf is uncertain, but often quoted as being approximately 50 percent. Much of this fresh water entering the west Louisiana shelf hugs the coastline and flows westward as a narrow current, the Louisiana Coastal Current. During most of the year, this current flows westward into Texas and even Mexican waters. During the summer months, though, strong southerly winds along the south Texas coast tend to push water back onto the Louisiana shelf and the current may reverse for a month to six weeks, particularly near the Texas-Louisiana border.

It is commonly accepted that the Mississippi River system discharge is intimately related to the development of summer hypoxia on the Louisiana inner shelf (Rabalais et al., in press). In its most simplistic form, the paradigm for the development of summer hypoxia is that the Mississippi and Atchafalaya Rivers load the coastal waters with massive amounts of new nutrients. Rapid phytoplankton growth results. These phytoplankton cells sink to the bottom and utilize oxygen, either through respiration or as they decay. Reoxygenation of the near-bottom waters is prevented by a strong density interface in the water column which results from light, low salinity water from the river system lying over heavy, saltier shelf waters. In order to understand the dynamics of hypoxia on the shelf, it is necessary to understand the physics of the inner shelf.

The Atchafalaya River empties into Atchafalaya Bay, a broad, shallow estuary, and then onto a broad, shallow region of the shelf. It dissipates energy through bottom friction and entrains ambient fluid through lateral mixing (Wang, 1984). In contrast, plumes from the dominant passes of the Mississippi River delta expand buoyantly and entrain water both from the sides and from below (Wright and Coleman, 1971). Studies of the Mississippi River plumes are maturing (e.g. Hitchcock et al., in review), while those of the Atchafalaya input are in their infancy.

The water mass modifications important to hypoxia should be described in a Lagrangian sense, i.e. following a water particle. We have only begun to address this type of description of processes on the inner shelf. Recent plume studies (Hitchcock et al., in review) have tracked water from the mouth of Southwest Pass for time periods of the order of one day, roughly the time necessary for the plume waters to merge into the Louisiana Coastal Current. Near surface current speeds can be as high as 1 m/s. Vertical entrainment rates at the base of the plume are estimated to range between 0.25 and 1 m/hr. Modification of nutrient concentrations (NO_3, SiO_4) during these early periods after water is released from the mouth of the river is not inconsistent with conservative mixing. The subsequent modification of waters entering the Louisiana Coastal Current have not been studied in a Lagrangian sense. Consequently, further downstream changes in water characteristics must be inferred from Eulerian measurements.

The seasonal changes in runoff to the Louisiana Coastal Current alter the stratification of the waters of the current (Wiseman et al., 1986). Fresh water floats atop salty water. Even during winter, when the river and nearshore waters are colder than the deeper and offshore waters, the freshness of the coastal waters maintains their lower density. The timing of floods and stormy weather is usually such that just as spring runoff is peaking, storminess is diminishing (Dinnel and Wiseman, 1986; DiMego et al., 1976). Thus, mechanical stirring and mixing of the water column by the wind is diminishing and maximum stratification establishes itself.

The distribution of stratification is modulated by other processes besides mixing. Winds cause currents which result in waters flowing towards or away from the coast, as well as parallel to the coast (Crout, 1982, Dagg, 1988). During 1986, a transect of stations was occupied 17 times across the inner shelf offshore of Cocodrie (Figure 29). Well mixed conditions were observed during low-runoff and high wind conditions at the beginning of the year. As the discharge increased and wind stirring diminished, stratification developed.

Even under low winds, though, the stratification strength varied significantly due to upwelling and downwelling (Wiseman et al., in review). During the summer, a secondary density interface developed near the bottom. Some years this second density interface is absent from our data. When it is present, it can be either due to salinity, due to temperature, or due to both. It is weaker than the main density interface, but very important to the distribution of hypoxia.

While water column stratification may be moderately constant for extended periods of time, strong currents may still be flowing through the region. These occur on a variety of time scales. Tides in the Gulf of Mexico are weak and so are the tidal currents (Science Applications International Corporation, 1989). Nevertheless, tidal currents stir the waters and interact frictionally with the bottom (Dinnel, 1988). Other currents also occur on similar time scales: inertial oscillations (Daddio et al., 1976) and currents driven by the sea-breeze system. On much longer scales, of the order of many weeks, the density gradients resulting from the spatial distribution of light, fresh water and heavy, salty water are associated with geostrophic currents. The observed shears due to these low frequency currents are very similar to those expected from theoretical considerations (Wiseman et al., in review). The most important current variability occurs on time scales of a few days to a few weeks (Crout et al., 1984; Chuang and Wiseman, 1983; Science Applications International Corporation, 1989; Wiseman and Kelly, 1994). These fluctuations are driven by wind forcing. They are also the strongest currents generally observed over the inner shelf. Flow reversals may occur in less than a few hours. Thus, cruise data that takes a week to collect may be sampling totally different flow conditions at the beginning and the end of the cruise. This makes data interpretation difficult. If one sees spatial variability, it is not clear whether this is the result of local processes or advection.

Strong, persistent seasonal stratification is a necessary condition for the occurrence of hypoxia (Figure 30); it is not clear that this is a sufficient condition. Furthermore, this strong stratification does not necessarily determine the structure of the hypoxic water mass. The oxygen sinks in the system are concentrated in the near-bottom regions of the water column. Weak near-bottom density interfaces confine the low oxygen waters near the bottom (Figure 31).

In summary, the physical processes active over the Louisiana inner shelf are important to the dynamics of hypoxia in the region. Mixing of river effluent with ambient shelf waters occurs rapidly after discharge. These waters then flow, generally, westward along the Louisiana coast carrying with them dissolved and suspended material from the rivers. The density structure of the waters within this flow are intimately tied to the occurrence, persistence, and structure of hypoxia. While the principal determinant of this density structure is the discharge from the Mississippi-Atchafalaya River system, winds and solar heating also modulate the stratification.

There remain numerous open questions:

- How much of the observed variability is the result of local mixing (and biological processes) as opposed to advection?
- What processes are responsible for cross-frontal exchange in the Louisiana Coastal Current?
- How are the processes associated with and influenced by the Atchafalaya River discharge different from those near the

Mississippi Delta discharge?

- What processes control the secondary density structures observed in the waters of the Louisiana Coastal Current?

Acknowledgments

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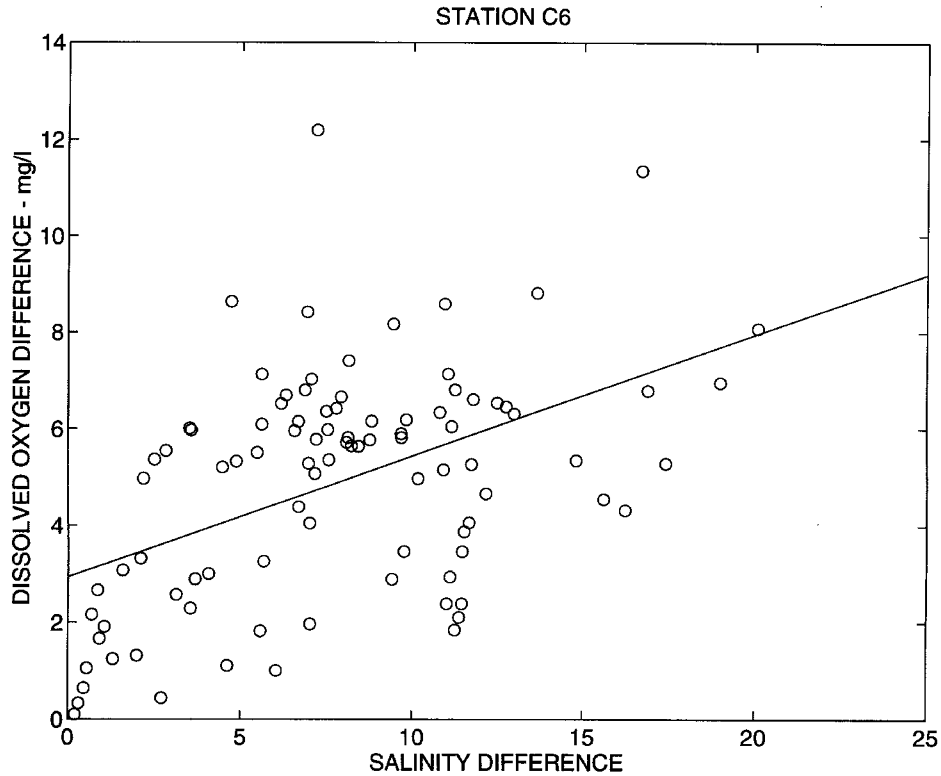

Figure 29.

Time series of salinity along an inner shelf transect offshore of Cocodrie, LA in 1986 (upper), time series of the associated Brunt-Vaisala period (middle), and time series of river discharge for 1986.

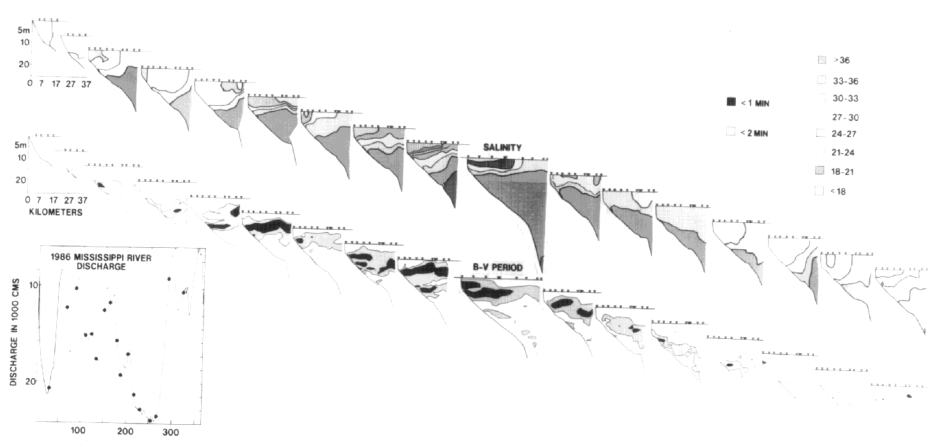

Figure 30.

Scatter plot of surface to bottom oxygen difference versus surface to bottom density difference from multiple occupations of the same station in 20 meters of water offshore of Cocodrie, LA in all seasons of the year. The straight line is a least squares fit to the data.

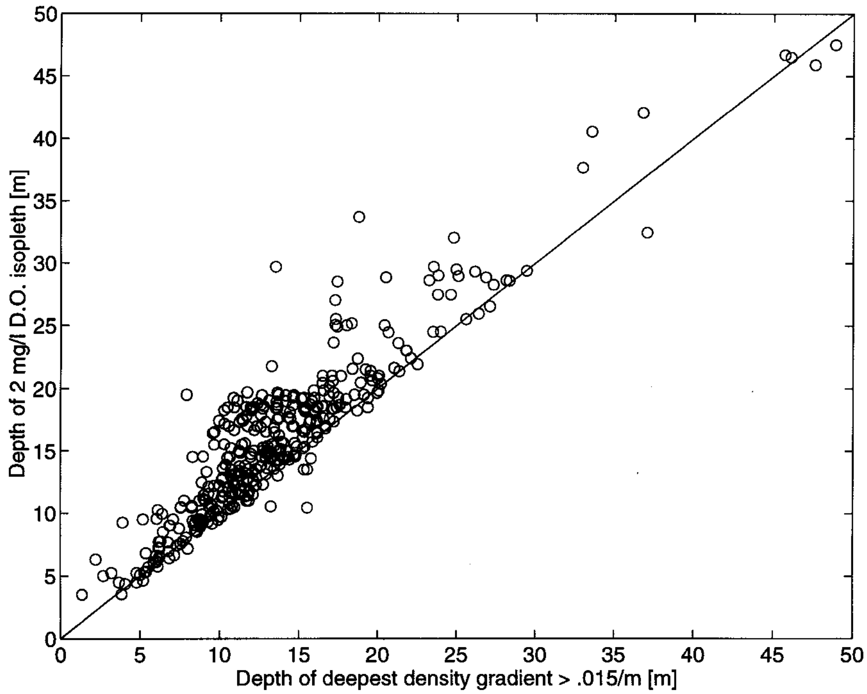

Figure 31.
Scatter plot of the depth of the 2 mg/l dissolved oxygen surface versus the depth of the deepest point where the density gradient exceeds 0.015 /m for 9 years of mid-summer cruise data from the west Louisiana inner shelf. The solid line has a slope of unity.

Presentation Discussion

William J. Wiseman (Louisiana State University—Baton Rouge, LA)

Len Bahr *(Louisiana Governor's Office— Baton Rouge, LA)* asked William Wiseman to discuss the mechanical impacts of significantly shortening the southern-most tributary of the Mississippi river and releasing the nutrient enriched water in an uncontrolled fashion into either the Barataria Basin or the Bertin Sound area, which are much shallower and less susceptible to stratification.

William Wiseman responded by saying that if the resulting stratification were reduced, the flow may short-circuit into deep water fairly quickly; particularly if it flowed through Barataria Bay, where there is a rapid increase in depth close to the shore. If there were a reduction in the salinity deficit of the water flowing onto the shelf, then the stratification of the Louisiana coastal current would be reduced and the bottom waters would be more easily re-oxygenated by weaker winds. If the River were allowed to flow past Morgan City, Louisiana and out through the Atchafalaya, the hypoxia conditions east of the Atchafalaya Delta would certainly be improved, and there would not be a major freshwater cap on top of that water. This process could potentially move the problem downstream into Texas waters.

Paul LaViolette *(Gulf Weather Corporation—Stennis Space Center, MS)* asked how satellite data would be used to help define the area of hypoxia.

William Wiseman did not know how satellite data would be used to define the hypoxia area, though he said it could be used to track plumes, plume dynamics, and occasionally the inner coastal current to analyze dynamics and mixing characteristics. There is a possibility the data could be used to gain an understanding of the distribution of phytoplankton in the surface layers which may indicate where the carbon source will settle.